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The Effects of Recycling on Fiber Characteristics

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ON FIBER CHARACTERISTICS

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Fiber Characteristics
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ABSTRACT

Recent trends in recycling indicate that future use will increase. This increase will bring a demand for the secondary fiber. Many technical questions have to be answered before recycling becomes an economical process. One of these questions is how the recycling process affects fiber characteristics. This thesis will deal specifically with this question.

INTRODUCTION

To satisfy demands for papermaking fibers in the 1980's, recycling will have to be increasingly relied upon because of the developing shortage of pulpwood. Ecological demands will also create pressure for the increased use of recycling. The Federal Governmental Purchasing Specifications will be changed to favor recycled products. A major reason for the government's interest in recycling is the problem of the disposal of solid wastes, a great deal of which is paper products. Recycling of waste paper can be used to help solve this problem and can also be a profitable venture for the industry as well. Improved waste paper collection and handling, especially the presorting of waste paper by the individuals discarding it will bring fibers back into the economy at their fullest value.

Our industry is facing a challenge today which has to be answered in the next few years. The paper industry is producing and consuming paper at steadily increasing rates. The industry will soon be at the point where the demand for wood pulp will be greater than the available supply of pulpwood. When this point is reached, recycling will have to be increased to satisfy our demands for papermaking fibers.

Recycled fibers can be and are being used satisfactorily in many grades of paper products. Processing secondary fibers, although simple in principle, is vastly complicated by high manpower needs and contaminants found in the waste material. The main assumption is that recycling is limited by technical aspects, but when it gets right down to it, the basic controlling factor is economecs.

In the past, studies have been completed on how recycled fibers affect strength properties of the sheet. These studies used handsheets for the paper and reported the strength decay in percentages. This thesis has used a pilot plant study to do the same thing. Different results were obtained since there are drastic differences between pilot plant and laboratory studies. The results are explained in terms of a model of fiber properties. The original batch of pulp was used through out the entire experiment. Once it is prepared and run of the fourdrinier, it was repulped and run again. A total of three runs were completed with strength testing performed at the end of each run. Fiber length testing will also be performed during each run to further characterize the stock.

LITERATURE SURVEY

In recycled fibers, losses in fiber strength are less significant than losses in bonding potential. Strength tests which are dependent on bonding have been shown to decrease with increased recycling (1). Also shown in work of this nature was that sheet strength decreased greatly if virgin pulp was beaten to a lower freeness.

Bond strength is the limiting factor in sheet strength since it is weaker than fiber strength. Work in this area was performed by Page (2), who concluded that since cellulose polymers are oriented along the length of fibers, fiber strength should occur from strong covalent linkages within the molecules, compared to fiber bonding which is a function of much weaker hydrogen bonds.

Some experiments recycled pulps six times to test effects. For these experiments (3), the pulp was dewatered by filtration and dried in bulk. Breaking length and density were found to decrease in some chemical pulps while tear and light scattering increased. Mechanical pulp properties remained constant over recycling.

There are many differences of opinion as to whether fibrillation or swelling are more important to bonding strength. Recycling could affect both. Swelling of the fiber in water causes a greater potential bonding area, due to an increase in surface area. The swelling also increases the flexibility and softness of the fibers, causing an increased tendency for the fibers to collapse, which in effect promotes more bonding.

Clark (4), in his work claims this is valid, but upon drying, the fiber shrinks to its original size, causing extreme stress on the bonds.

Another theory of cellulose-water interactions in drying was developed by Giertz and Christensen (5). They theorize the drying to take place in two phases. First, free and surface water is driven off, drawing the fibers closer together through surface tension forces. In the second phase, water within the fibers evaporates and causes shrinkage. This shrinkage allows fibrils to align themselves so hydrogen bonds can form.

Ceragioli (6), developed a theory on the causes of strength losses due to drying. He theorized that an increased orientation of water molecules develops in cellulose molecules causing fibers to become weakly bonded to each other. These bonds reach their maximum strength when the last of the water is driven off. Bonds formed in this manner do not seem to be completely eliminated by re-wetting with water. This is only one model of the drying effects of cellulose.

Another is that of Stone and Scallan (7). They propose that water imbibed by the fiber is contained primarily in pores located between concentric layers of cellulose in the cell wall and also in a form of molecular association with the cellulose. This water was found to cause the swelling of the fiber along with an extremely large increase in specific surface area, a factor of about 200. It was noted that upon drying, the size of the pores did not change, although the volume did decrease, due to shrinkage. They also suggest that the drying begins at the exterior of the fiber and progresses radially inward. The outer most pores, closing in the early stages of drying, do not reopen when re-wetted. This theory suggested that the irreversible drying occurs in the early stages of the closed pores. More stringent drying affects the reswell-ability due to a reduced amount of reopened pores.

Giertz (8), predicted capillary-condensed water can be evaporated without changes. Then, when water is added again to these fibers, they reswell to original volume. This process is reversible. The irreversible change occurs when boundry water evaporates. He found that it was possible to dry a sheet uniformly to 85% solids without altering its properties. He mentioned that drying techniques in the mill over dries the outside of the sheet, causing much of the irreversible structural change before 80% solids is reached. By heating, some of the original swelling volume will return. He states 'drying moves the pulp backwards on the beating curve'.

Sheet properties are very important in the aspect of paper quality. Different end uses require different sheet properties. Some paper requires a strong sheet and some do not. The end use of the paper determines the properties which are necessary. Strength tests are used in paper testing to determine strength properties in the sheet. These values are then used to tell whether or not the paper is acceptable.

Mullen, one test used in the determination of paper strength, measures the force required to push a hole through a sample of paper. Pressure is measured as a diaphragm is forced through the sample.

The mullen test is very sensitive to bonding. The more bonds in the sample being tested, the larger the mullen values. It is impossible to express the strength of paper in terms of a single factor because sheet strength is a complex function of fiber length, condition of fiber surface, size of the fibers, orientation of the fibers in the sheet and density of the sheet. Of all the factors listed, fiber to fiber bonding is most significant. Fiber length is a property to be considered in paper making because after as much fiber to fiber bonding as possible has taken place, the strength of the paper depends principally upon the length of its fibers. The longer the fibers, the less chance there is for slippage between the fibers when the sheet is subjected to stress. Furthermore, the greater the fiber length the greater opportunity for fibril formation. Hence, pulps which possess greater fiber length generally have a higher capacity for interfiber bonding.

Recycled fibers are fibers that had already been beaten at least one time. When beaten again, the fibrils may be broken from fiber surfaces reducing their potential to bond later. This would cause the fiber shafts to become separated from each other. The fiber shafts could still have small fibrils and microfibrils wrapped around them from the previously adjacent fiber. The once dried and now re-wetted fibers are usually stiff and brittle, which would tend to cause more cutting during repulping and in turn not provide as much area for bonding.

The fold test is a test of strength designed to determine how much abuse a sheet can take without breaking. Fiber flexibility strongly influences fold test values. Another factor that is very important is fiber length, considering the test area of the fold test is very small. When considering such a small line, the only substance would be either a fiber spanning the distance or a fiber bonded to another fiber with the bond in the line. The more fibers that span the distance will increase the strength of the fold test. Flexibility and fiber length both contribute to the strength value, but as the average fiber length gets smaller, the percentage of bonds in the test line will increase, causing fold values to go down.

When repulping, all that is being accomplished is the separating of fibers from one another. The fibers tend to become bulkier because the bonds, fibrils, and microfibrils tend to stay on the main trunk of the fiber. When these bulkier fibers are used in the making of paper, the density tends to decrease since the fibers can no longer lay as flat as before. As density decreases, fold goes down.

The tensile test is also another important test in determining strength qualities of a sheet of paper. The tensile test determines the force in kilograms necessary to pull apart a sample of paper that is fifteen millimeters wide. Deficiencies in strength of paper must be attributed to lack of bonding and not to the lack of fiber strength. The actual tensile strength of paper in the direction of its greatest strength ordinarily amounts to much less than the theoretical tensile strength which would be obtained if the individual fibers were held together by forces equal to intrafiber bonds (1).

The impression should not be given that fiber strength is unimportant in sheet strength because it has a very significant influence in its effect on the initiation of rupture in the tensile test. A large percentage of the individual fibers are broken or pulled apart during tensile failure of paper. This high percentage of broken fibers during tensile testing takes place in spite of the high tensile strength of the individual fibers.

Tensile increases as beating increases only because as beating increases, bonding increases. Fiber length and strength do not greatly affect tensile. It is the amount and distribution of bonds. For recycled paper, the stock is not, in a sense, being beaten or refined, but is being defibered. During the beating stage of recycling fibers, no further advantageous fibrillation takes place. The fibrils and microfibrils of fibers are ripped off and stay adjoined to the other fibers to which they were bonded. This drastically cuts down the surface area of these fibers. With the lower surface area, the amount of surface to surface bonding will not be as great. This will tend to cause less bonding and uneven distribution will result. The drying of pulp brings about this change in the beating properties. Once the pulp has been dried, loosening the fibers becomes more difficult because of some drying of residual hemicellulosic material and also some contraction of the cellulose structure.

The tear test is another test that is used to determine strength qualities of a sheet of paper. It measures the force required to tear a piece of paper after the tear has been started. Fiber length is a pulp quality which affects the values of the tear test greatly. As fiber length increases, the tear increases, due to the increase of frictional drag work per fiber. If the fiber is to be pulled out intact, the longer fiber would require more work.

The brittleness of pulps being recycled would cause cutting during beating. The fibers would become bulkier and have less surface area than that of the fibers of the previously made web. Due to this bulkiness of the fibers, when the sheet is reformed, the fibers will not lay as close together and in turn, not as much bonding will take place. Since the amount of bonding goes down, this does not mean that more fibers will be pulled out than before, but due to the brittleness of the fibers and the cutting taking place, the shorter average fiber length will decrease tear due to the less frictional drag work needed to complete the tear.

Fiber length is a very important parameter in terms of strength of paper. The longer the fiber, the better chance of a stronger sheet per species of wood exists. Fiber length can be measured in many ways. Using a microscope, the Clark classifier, or the short span tensile tester are three methods.

Studies have already shown that the Clark classifier and the microscope correlate but whether or not the short span tensile test correlates with the Clark classifier has not been dealt with in detail. This thesis will attempt to obtain data concerning this point.

When the tensile test is performed on the Instron tensile tester, the network property is measured. Since the span is several inches in length, the network structure must be broken and this is the rupture. Since the length of fibers is only a few millimeters long, there is no way for them to span the entire length of the test area. This indicates that failure load of the paper strip is solely dependent on network structure. As the span is decreased, tensile should become higher on the average. The strip of paper is only as strong as its weakest point. The longer the paper sample, the greater the chance for a weak spot. As the span decreases down to zero, there would be no network structure involved, only the fibers would be clamped by the two jaws. The short span tensile tester does this measurement.

The strength of paper usually depends on fiber strength, fiber length, fiber orientation, and the degree of fiber to fiber bonding. The short span curve can be analyzed to distinguish these four factors from one another. This means that not only does it analyze the quality of the individual fibers, but also, as the span is increased, the quality of paper as a network structure. It will help distinguish the extent of help that a particular characteristic contributes to paper and pulp.

During a short span tensile test, there will always be some sort of network structure. This is due to the laws of friction. When the jaws clamp down at zero span and begin to pull apart, some slippage will occur. As the slippage occurs, the distance between the gap becomes greater. As the slippage increases, the gap increases causing the amount of fibers bridging the span to decrease. This results in a false indication of the fiber length. In theory, as the span in increased, the number of fibers that bridge the span decreases, causing the failure load to decrease. When the span is equivilent to the average fiber length, using an unbonded structure such as an unsized sheet soaked in water, the force should be zero. A plot of load vs span will extrapolate to zero force allowing an estimation of average fiber length. Hence, as the slippage increases, the span will prematurely increase, causing less fibers to bridge, which will affect the load force needed for the break. By increasing the clamping pressure, more fibers would be securely clamped and this would prevent some slippage. The more fibers that are clamped tightly, the higher will be the failure load. Increasing the pressure at the clamp will reduce the residual span and increase the number of fibers that will damage the fibers. It has been determined that a clamping pressure between sixty and seventy psi will result in the maximum values obtainable.

A second method of measuring fiber length during the work in this thesis will be the Clark classifier. This test has been used for many years to establish average fiber length of pulps. The method uses screen classification as the means for measuring fiber length. Fiber classification by screens is based upon the mechanical segregation of the fibers into classes of definite fiber length and the determination of the weight of fibers in each class. The clark classifier is one of two principle screen classifiers, the other being the Bauer-Mcnett.

Original data obtained with screen classifiers are in the form of percentage weight distribution between screens of different mesh. In making calculations of average fiber length from the amounts of the various screen fractions, it must be assumed that all the fibers have the same specific gravity and same diameter and that each unit weight has the same total fiber length, or it must be assumed that the percentage by weight of a fraction represents the relative total number of fibers in that fraction (10). Results are converted to average length values by first establishing factors showing the relationship between mesh size and weighted average fiber length. The average length of the fraction collected on the coarsest screen will vary according to the pulp used, and consequently separate factors must be determined for each different classification condition used. The fines fraction which passes through all screens and is lost in the effluent is assigned an estimated value. For the Clark classifier, using a five gram sample, 12.5 liters of water per minute, and a classification time of four minutes, the following weighted average fiber length by weight were obtained for each compartment: (12)

On 14 mesh	3.85 mm
Between 14 & 28 mesh	2.70 mm
Between 28 & 48 mesh	1.70 mm
Between 48 & 100 mesh	.95 mm
Through 100 mesh	.10 mm

These values will be applied to the weights obtained from each compartment in order to establish an average fiber length.

EXPERIMENTAL

A hydropulper was to be used to defiber the bleached softwood pulp in 220 pound batches at 4.5% consistency at 170°F. After pulping, the slurry was to be pumped to the hollander beater. In the tub, the stock will be pumped through the Claflin refiner for twenty minutes at a setting of forty killiwats per hour. Once the paper is made, it was to be slabbed down, weighed, and repulped and refined in the same way for the second and third runs. However, the original experimental design had to be changed for a number of reasons. The stock had to be diluted before pumping and the increased volume was greater than the capacity of the hollander tub. Accordingly, pulp was still in the pipelines and hydropulper when the hollander tub was full, and the stock left in the hydropulper had to be sewered. These losses totaled approximately 50% of each run, leaving only sixty pounds of stock for the third run. The original plan also called for the amount of refining of the stock on each run to be the same. The stock, after being refined for the third time, was too low in freeness to run on the machine. Without the third run, the experiment was incomplete, therefore the decision was made to start over.

The new procedure required the hollander tub to be used as the recycle tank with the roll raised to eliminate refining. The consistency of the stock in the tub and the defibering time were held constant at 4.9% and 30 minutes. The pulp was run on the fourdrinier without any chemicals being added and without calendering to keep the system simple. All machine parameters, including press weights, speed, and slice were kept as constant as possible to form a 50 pound per ream sheet (25x38x500). In recycling this sheet, only the work of defibering would be required. The freeness of the stock was taken to characterize the stock before each run.

Samples of the paper at the winder were obtained at the end of each run and placed in the constant humidity room. Tensile, fold, mullen, short span tensile, and tear tests were run on these samples to determine what types of fiber characteristic changes have occurred after recycling. Stock from the hollander tub was also saved to run fiber classifications to further identify any changes.

DISCUSSION OF DATA

Freeness values of the runs remained constant for runs #2 and #3, but had shown an initial drop from the first run. Many factors, or combinations of factors can cause freeness to decrease. Decreased fiber length, increase of fines, increased fiber flexibility and increased fiber fibrillation can all decrease freeness.

Average fiber lengths were estimated by two different testing procedures. The first was the Clark classification test. The data showed the average fiber lengths, derived from values obtained from Reed and Clark,(12), remained constant for the second and third runs but had an initial drop from the first run.(Table I) This follows the same pattern as the freeness.

The Pulmac short span tensile was the second fiber length test used. A definite value of average fiber length is not determined, but a plot of breaking force versus span can be extrapolated to zero force to obtain a fiber length estimate. (Table II) Since the data points of each of the runs of the short span tests are so close numerically, the difference between the plots is not significant and therefor were not plotted, but values are presented and include the resulting values of average fiber length from the regression analysis.

Fines level as determined from the Clark classification tests is also shown on Table I. The test is based on an initial amount of stock of five grams. The percent fines is calculated from the difference between the total weight retained in the four vats and the initial five grams. The accuracy of this measurement is dependent upon the accuracy of the initial five gram measurement. The stock obtained from the hollander tub after defibering was diluted to less than .3% consistency to allow accurate measurements for the test.

Figure 1 shows the fines level was similar for runs number two and three but showed an increase from number one. Again, this could explain the results of the freeness tests. The increased fines from run #1 to run #2 indicates fiber cutting. Figure 1 shows that distribution shifted slightly to a shorter average fiber length. Since the fines level remains constant for runs #2 and #3, further cutting when defibering run #3 seems unlikely.

Tear, fold, mullen and tensile tests were performed on the dried paper web to further characterize the stock and the data obtained are shown in Table II. The mullen and tensile tests, which are a measure of bonding, increased for each run indicating increased bonding, which could be the result of either increased fines or flexibility. The fold test, a measure of bonding and fiber flexibility, increased with each run indicating that the flexibility of the pulp also increased. The fold test is also affected by fiber length. The decrease in fiber length was not great enough to overcome the increased fiber bonding. The tear test is also affected by fiber length, and the drop in MD tearing resistence for the third run reflects the drop in fiber length. The initial rise, from run #1 to run #2 is less than 10% which is relatively insignificant.

These strength tests and the fiber length tests combine to characterize the stock and give an indication of what fiber characteristics changes took place due to the recycling process. The freeness values dropped because of a possible combination of decreasing fiber length, increasing fines content and increasing fiber flexibility or fibrillation. The combination of these factors should decrease the freeness more than the freeness values indicate, but the contribution of each is very small. The fiber length decrease was very small and should not greatly affect the freeness values. The strength test results were again very small increases, which should not greatly affect the freeness of the pulp. The freeness test itself is not a very specific test and the differences could have been greater. The differences between the tests of the runs were not very significant, but however small they were, they were consistent.

The recyling process refined the fibers slightly, increasing tensile and mullen. The fibers that were recycled were not stiff and brittle, indicated by the increase in the fold test and cutting was not great, indicated by the increase in the Clark classifications. These factors produced an increased area available for bonding.

The bulk of the sheet decreased causing an increased density, indicated by the increase in the fold test values. This decrease in the bulk is due to the ability of the fibers to separate efficiently so that the fibrils and microfibrils will remain with the original fiber and not on the trunk of the fiber to which it was previously attached. These fibers tend to remain less bulky and have a greater surface area for bonding.

CONCLUSIONS

Previously, it was determined that stock looses strength due to recycling. This research, which isolated the recycling process, concludes that recycling does not adversly affect pulp quality. The recycling process actually increased pulp strength in this study.

This piece of work differs in it's conclusion from previous conclusions of similar work since the two are very different in procedure. Refining of the stock was an element that greatly affected the outcome of the results in other works. The increased refining of the pulp reduced the surface area available for bonding, made the sheet bulkier, decreased density, and decreased the average fiber length, indicated by the results of the strength tests. With the refining eliminated, as in this work, the opposite occurs. The average fiber length decreases slightly, but the surface area available for bonding and density increased and bulk decreased. The system studied in this pilot plant level experiment was very simple. It was an unsized, uncalendered paper, both of which can increase the work needed to recycle causing greater damage to the fibers. The amount of work on the fibers determine its strength characteristics. It is very possible that a sized paper, or even one that has wet strength additives could show a strength loss. Future work could evaluate these proposals with different papers.

TABLE I

Retained Fibers of Mesh Sizes for Clark Classifications

	RUN #1 %	RUN#2 %	RUN#3 %
14 mesh	1.3	.82	.61
14 - 28 mesh	62.42	57.94	53.13
28 - 48 mesh	23.15	22.49	23.65
48- 100 mesh	11.33	14.74	17.71
Fines	1.38	3.97	4.96
Average Fiber Length	2.25mm	2.12mm	2.10mm

All values are percentages unless otherwise stated.

TABLE II

Strength Test Data

		Run #1	Run #2	Run #3
Fold (MIT)	CD	28.3	35.4	44
	MD	144.1	180.4	330.56
Mullen (PSI)		26.32	28.48	33.09
Tear (gm)	CD	37.62	41.14	31.3
	MD	33.11	38.8	26.82
Tensile (Kg)	CD	5.82	5.75	5.28
	MD	12.77	13.03	13.32
Basis Weight (/ream)		50lbs	50lbs	50lbs

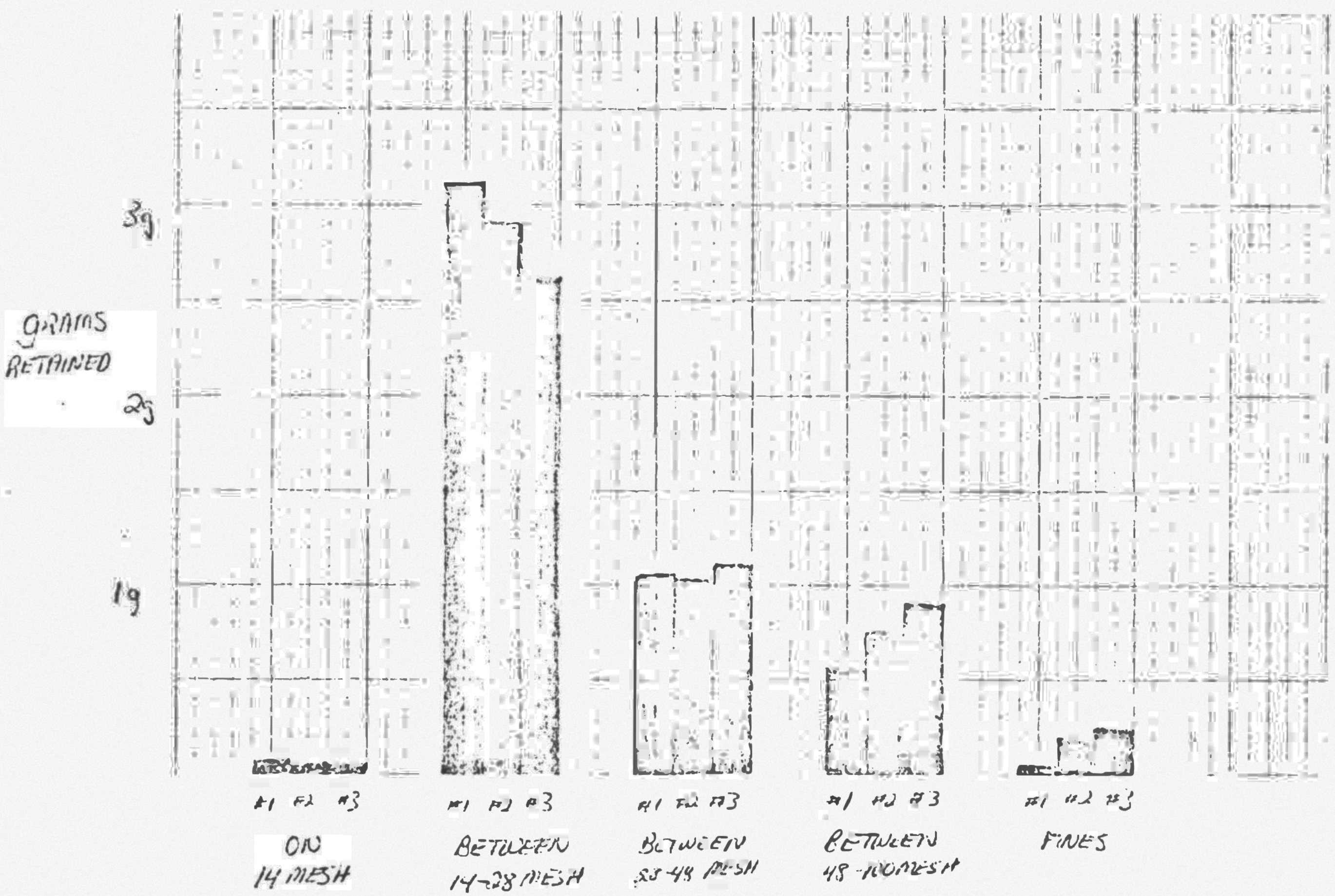
TABLE III

Short Span Tensile Data

SPAN	RUN #1 (Psi)	RUN #2 (Psi)	RUN #3 (Psi)
0mm	28.3	28.2	28
.2mm	22.725	22.325	21.375
.4mm	21.25	20.25	19.7
.6mm	18.25	18	17.25
.8mm	14.95	14.85	14.4
1.0mm	10	10.325	9.9
1.3mm	9.025	8.2	8.175
1.5mm	8.375	8.05	7.925
1.75mm	7.6	6.525	6.4
Average Fiber Length	2.05mm	2.01mm	2.00mm
Slope	-.0775	-.0773	-.0785

All values are averages of four tests.

FIGURE 1
CLARK CLASSIFICATION FOR
AVERAGE FIBER LENGTH



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